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PERFORMANCE EVALUATION OF THE SPRUCE BUDWORM EGG MASS COUNTER: PROTOTYPE II

CONTENTS

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PERFORMANCE EVALUATION OF THE SPRUCE BUDWORM EGG MASS COUNTER: PROTOTYPE II

by

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ABSTRACT

A performance evaluation of the Prototype II automated spruce budworm egg mass counter was conducted. Data used in the evaluation was obtained from 525 branch samples representing three tree condition classes in each of the five primary host species found in the major outbreak areas throughout North America. The correlation between the machine counts and manually counted number of egg masses was, for the most classes, not significant. Even for the three classes where the correlation was significant, the relationship between the two counts was not strong enough to warrant the use of machine counts to infer the number of egg masses. Spatial and spectral analyses of the detailed machine data available for 239 branch samples improve the correlation only very slightly. Improvement in the procedures for training the machine to recognize egg masses must be achieved before the automated egg mass counter is ready for operational use.

INTRODUCTION

The spruce budworm, Choristoneura fumiferana (Clemens), and the western spruce budworm, C. occidentalis, Freeman, are two of the most destructive forest insects in North America. Sound forest management decisions to minimize loss due to these insects depend on prompt detection of changes in the spruce budworm populations. Knowledge of egg mass abundance and condition provides managers with an early and relatively reliable indication of potential damages, especially in high populations. This timely information expedites planning for future management activities (Allen et al. 1984).

Sampling tree branches for egg masses is one of the most commonly used methods to determine spruce budworm population trend. Tree branches are cut

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and brought to the laboratory where workers examine the branches and count the number of egg masses in a dark room equipped with ultraviolet light. However, manual counting of spruce budworm egg masses is tedious, time consuming, and costly. In addition, counting accuracy is suspect unless reexamination of foliage is conducted to ensure that all egg masses are accounted for. The accuracy of finding and counting egg masses has been found to be related to the budworm population level, the nature of foliage examined, and the worker's experience (Morris 1951, 1955).

To improve the efficiency of egg mass sampling, the USDA Forest Service undertook a study to determine the feasibility of developing an automated egg mass counter. Results of this study showed that "on the basis of violet and green fluorescence spectra, egg masses of the spruce budworm are distinguishable from most other fluorescing objects on balsam-fir foliage" (Carniglia et al. 1977). Point by point fluorescence measurements (of egg masses, buds, lichens, pupae, twigs with bark, bare twigs, staminate flower, silk webbing, and needles) displayed a distinct spectral region for spruce budworm egg masses in the scatterplot of peak violet intensity versus green/violet ratio (Figure 1).

The Prototype I egg mass counter was developed by the University of Maine, Department of Electrical Engineering, in cooperation with the Northeastern Forest Experiment Station. Prototype I was later tested by the Department of Electrical Engineering and Maine Forest Service. Results of the test indicated that manual counts of new and parasitized egg masses can be reliably predicted (R^2=0.97) from electronic counts (USDA Forest Service 1979). Electronic counting was also shown to reduce processing time considerably, from a mean of 29.5 minutes per branch for the manual method, to 8.6 minutes for the electronic method.

Encouraged by these results, an automated spruce budworm egg mass counter (Prototype II) was developed through the efforts of the CANUSA Spruce Budworms Research, Development and Application Program, Northeastern Forest Experiment Station, University of Maine, and the Missoula Equipment Development Center in Missoula, Montana. During 1984, a performance evaluation of the unit was conducted. Objectives of this evaluation were[2/]:

1. Develop and test the regressions of egg mass counts by conventional means (manual counts) versus machine counts for various host species, geographic regions, and foliage conditions.

2. Estimate the efficiency of the machine counter by comparing times required to perform hand counting and machine counting of branch samples.

3. Provide an opportunity to gain user experience with the egg mass counter.

This report describes the results of the work.

[2/] Ciesla, W.M. 1984. Work plan - performance evaluation of the spruce budworm egg mass counter: prototype II (EMC). USDA Forest Service, Forest Pest Management/Methods Application Group, Fort Collins, CO 9 pp.

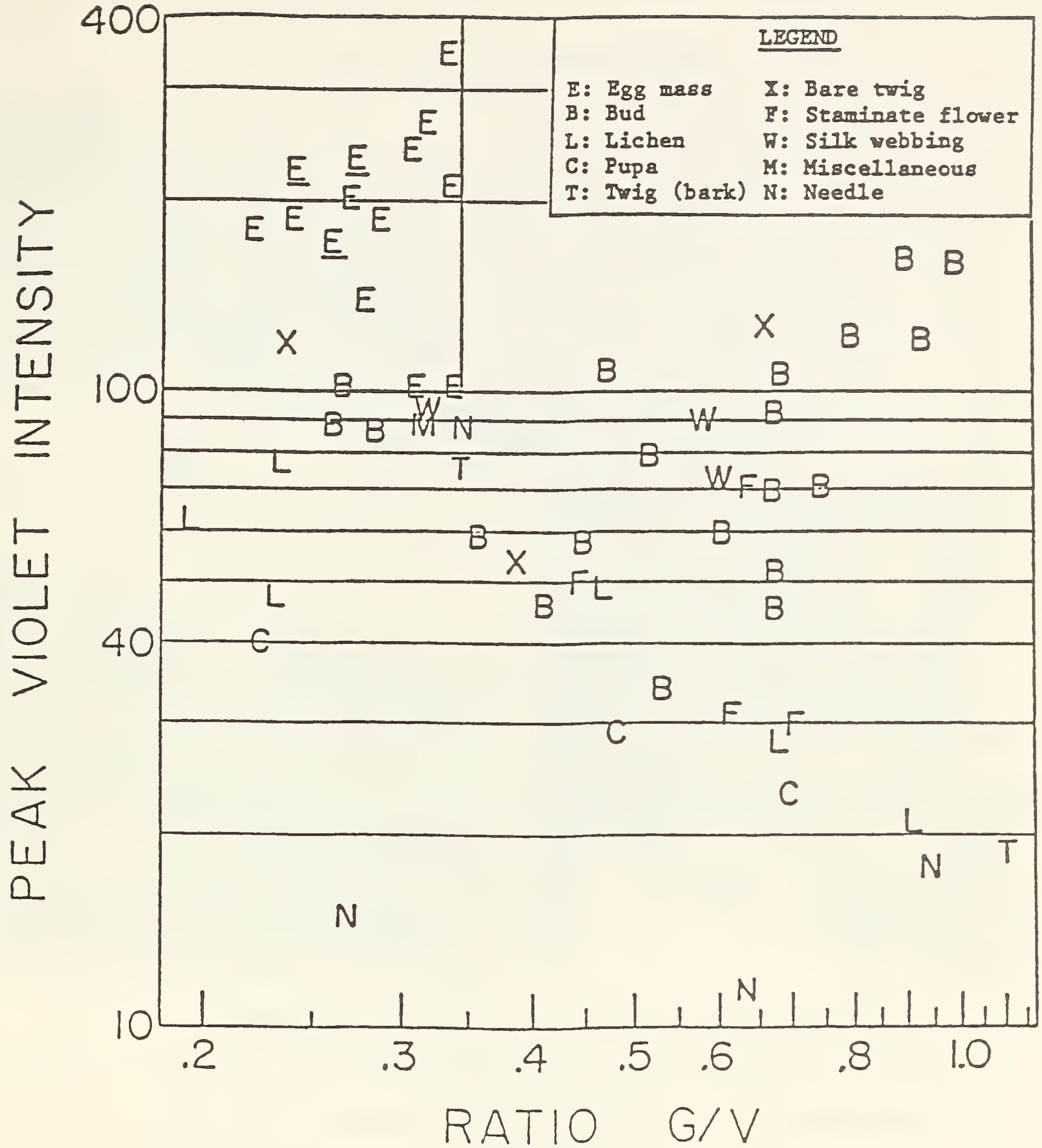

Figure 1. Distribution of Egg Mass and Other Objects in Peak Violet Intensity and Green/Violet Ratio Space (Carniglia et al. 1977)

THE PROTOTYPE II EGG MASS COUNTER

Prototype II, referred to henceforth simply as the egg mass counter, was designed to improve upon the previous version of the automated egg mass counter by replacing the analog devices of the earlier machine with digital electronic techniques and components. The digital approach was believed to offer the following advantages: (1) eliminate noise susceptibility; (2) provide a precision of scanning control unattainable in analog systems; and (3) facilitate changes in the operating parameters through software changes from the keyboard instead of manual adjustments of electronic controls or physical changes of hardware components (Jennings et al. 1982).

The machine is comprised of (1) a conveyor belt that is advanced by a stepper motor and its driver electronics; (2) an ultraviolet light source and associated beam forming optics; (3) a servomechanism controlled beam positioning mirror and associated electronics; (4) a fluorescence assessment assembly of filters and photomultiplier tubes; and (5) a microprocessor-based computer system which coordinates all the functions and processes the signals from fluorescent objects (Figure 2). A detailed description of the machine is provided by Jennings, et al. (1982).

MATERIALS AND METHODS

BRANCH SAMPLING AND STORAGE -

Branches used for this evaluation came from the primary host species found in the major outbreak areas throughout North America. Collections were made from five combinations of location and host tree:

1. Northeastern U.S. and Canada - balsam fir, *Abies balsamea*.

2. Northeastern U.S. and Canada - red/black spruce, *Picea rubens*/*P. mariana*.

3. Northwestern U.S. - Douglas-fir, *Pseudotsuga menziesii*.

4. Northwestern U.S. - grand fir, *Abies grandis*.

5. Southwestern U.S. - white fir, *Abies concolor*.

Branches were cut from 35 trees in each of three tree condition classes (5 X 35 X 3 = 525 branches).

Tree classes were defined relative to degree of cumulative defoliation and infestation age as follows:

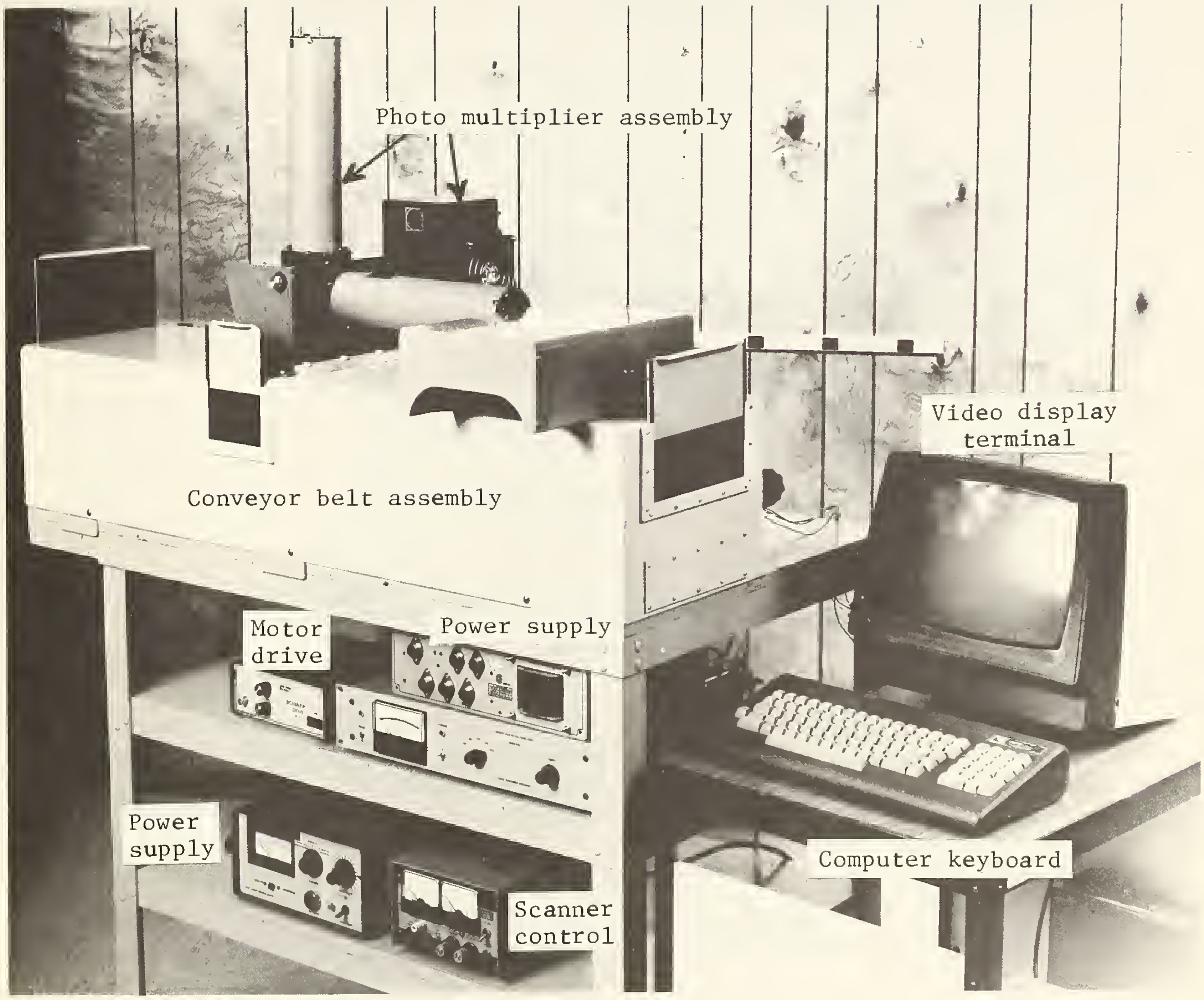

Figure 2. Automated spruce budworm egg mass counter Prototype II (Photograph courtesy of the Missoula Equipment Development Center).

1. Good: Current defoliation light to moderate, previous damage light to none, tree appears generally healthy.

2. Intermediate: 50 to 70 percent crown intact, but previous damage visible.

3. Poor: Some current damage present, post damage highly evident, lichens abundant on branches, tree may have dead tops.

From each tree a 70 cm midcrown branch was cut, bagged, and sent to Cooperative Forestry and Pest Management, Northern Region USDA Forest Service, in Missoula, Montana, for processing. Branches came from the field with the following information:

1. Collection date and crew.

2. Location, tree species and tree condition class.

3. Branch number (1 to 105), length and width (cm).

4. Whole tree defoliation estimate (nearest 10 percent).

Branches were held in cold storage (1°C) at Missoula until processing.

DATA COLLECTION -

In addition to data recorded in the field, machine counts (number of "hits") for bottom pass and top pass, manual counts of new and old egg masses for top and bottom sides, and start and stop times for all tasks in both machine and manual counting were recorded for all 525 branch samples. In addition, detailed machine data was recorded at every point where a hit occurred for 239 of the 525 branches (Table 1). This set contains information on location, tree species, tree condition class, type of pass (top or bottom), hit number, along belt and across belt coordinates (X and Y), and violet and green reflected light intensity (Figure 3). Count data were recorded on data sheets shown in Figures 4 and 5.

MACHINE COUNTING PROCEDURE -

To facilitate passage of samples through the input chute and to conform with belt dimensions, branch samples were cut into small segments and when necessary for proper orientation, the top surface was marked with a felt tip marker.

This clipping process is the same as that which would normally precede manual counting. This meant foliage went to the examiners for the manual counting precut. Branch segments were passed twice through the egg mass counter; once for the upper surface and once for the lower surface according to procedures described in Jennings, et al. (1982). Branch segments were bagged at the discharge chute and returned to cold storage to await manual counting.

SAMPLE NO	HIT NO	BLT POS	LOCAT	VIOLET	GREEN
RS39B2	1	432	84	246	49
RS39B2	2	739	85	130	40
RS39B2	3	1494	60	130	41
RS39B2	4	1496	61	212	43
RS39B2	5	1496	66	211	54
RS39B2	6	1496	68	245	87
RS39B2	7	1497	66	167	53
RS39B2	8	1497	67	170	38
RS39B2	9	1497	70	175	64
RS39B2	10	1498	70	245	70
RS39B2	11	1499	68	139	38
RS39B2	12	1499	70	204	81
RS39B2	13	1501	71	151	40
RS39B2	14	1504	72	133	50
RS39B2	15	1770	72	240	74
RS39B2	16	1772	69	157	55
RS39B2	17	2450	57	170	37

SAMPLE NO	HIT NO	BLT POS	LOCAT	VIOLET	GREEN
RE39T2	1	1148	76	221	51
RS39T2	2	2277	66	157	40
RS39T2	3	2277	67	150	42
RS39T2	4	2530	58	128	31
RS39T2	5	2531	58	229	47
RS39T2	6	2532	58	126	27

Figure 3. Detailed data recorded for each hit containing Sample No., Hit No., Belt Positions (x, y), Violet Intensity and Green Intensity.

Table 1. Distribution of branch samples among the location/host/tree condition classes.

Location/Host Class	Tree Condition Class		
	Good	Intermediate	Poor
Northeast:			
Balsam fir	35(35)	35(29)	35(27)
Red/Black spruce	35(23)	35(28)	35(27)
Northwest:			
Douglas-fir	35(35)	35(35)	35(0)
Grand fir	35(0)	35(0)	35(0)
Southwest:			
White fir	35(0)	35(0)	35(0)
			N = 525(239)

Note: In parentheses are numbers of branches for which detailed hit data was recorded.

E M·C Date Form

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Field Date Section

Collection Date	Day/ Month/ Year ______________________			Crew	________________	
Location (circle one)	ME	MT	ID	NM		
Host Tree (circle one)	BF	RS	Df	GF	WF	
Class (circle one)	Good	Int	Poor			
Branch # __________	Length _________	cm	Width _________	cm		

Current Whole Tree Defoliation (nearest 10) ________ percent

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Laboratory Data Section

	Start	Stop		
Second Cutting	_________	_________		
	Start	**Stop**	**Date**	**Initials**
Manual Examination #1	_________	_________	_________	_________
	_________	_________	_________	_________
	_________	_________	_________	_________
Manual Examination #2	_________	_________	_________	_________
	_________	_________	_________	_________
	_________	_________	_________	_________

Figure 4. Form for recording branch identification and manual examination start-stop times.

Egg Mass Classification

Location: ME MT ID NM — Host: BF RS Df GF WF — Class: Good Int Poor

Date		Branch	Manual Examination #1						Manual Examination #2					
Day	Month	#	New 0	New <50	New >50	Old	Start	Stop	New 0	New <50	New >50	Old	Start	Stop

Figure 5. Manual Count Data Recording Form

MANUAL COUNTING PROCEDURE -

Manual foliage examination was done with the aid of longwave ultraviolet illumination according to procedures prescribed by Acciavatti and Jennings (1976) and Dixon, et al. (1978). Fluorescing objects were removed and placed in petri dishes. Two complete examinations of each branch by different examiners were done to maximize egg recovery. Then, under white light and with the aid of stereomicroscopes, egg masses were separated from trash items and categorized as new or old (deposited in a previous year) egg masses. Egg counts were recorded by needle surface (top or bottom), new or old, and amount of parasitism. New and old masses were retained in separate dishes for further study.

MACHINE DATA REDUCTION -

Machine detailed outputs consist of location/host/tree condition and branch identification, hit number (when reflected light readings fall within the spectral region of egg masses), X and Y coordintes of the hit location on the machine conveyor belt, and light intensities in the violet and green spectral bands. Machine estimates of the number of egg masses on each branch were derived from this data. Two types of analyses were performed in data reduction: (1) spatial analysis of hit coordinates to eliminate multiple counting of each egg mass; and (2) fine tuning the machine calibration (spectral analysis) by redefining the hit-no-hit thresholds.

SPATIAL ANALYSIS - The size of spruce budworm egg masses varies approximately from 1.25 to 1.50 mm in width and 4.5 to 10.0 mm in length. Because scanning spot size was set at 1.5 mm X 1.5 mm (beam width and size of incremental movement of the scanning beam), it was possible that several adjacent "hits" (up to 6) could be from a single egg mass. This may partially explain the high number of hits by the machine, which was more than three times the actual number of egg masses.

On the other hand, because the minimum length of egg masses was approximately 4.5 mm, single hits may be from other objects with similar spectral characteristics as egg masses in the ultraviolet reflection.

To determine the effects of the geometry of egg masses on the scanning spot, hence, the accuracy of machine count, a spatial analysis of the data was performed. The analysis procedures shown in the flowchart (Figure 6) was designed to perform two functions: (1) combine up to six adjacent hits into a single count; and (2) eliminate clusters of hits less than a set minimum size from the counts. The combination of these two functions was controlled by setting minimum and maximum numbers of adjacent hits in an egg mass (Figure 7 is an illustration). The combinations used were (1,6), (1,5), (1,4), (1,3), (1,2), (2,6), (2,5), (2,4), (2,3), (2,2), (3,6), (3,5), (3,4), and (3,3).

For each of the above minimum-maximum combinations, the reduced number of machine counts were computed for the 239 branches and the new counts were correlated with the hand-counted numbers of egg masses. Correlation coefficients between manual counts and machine counts were computed for each location/host/tree condition class.

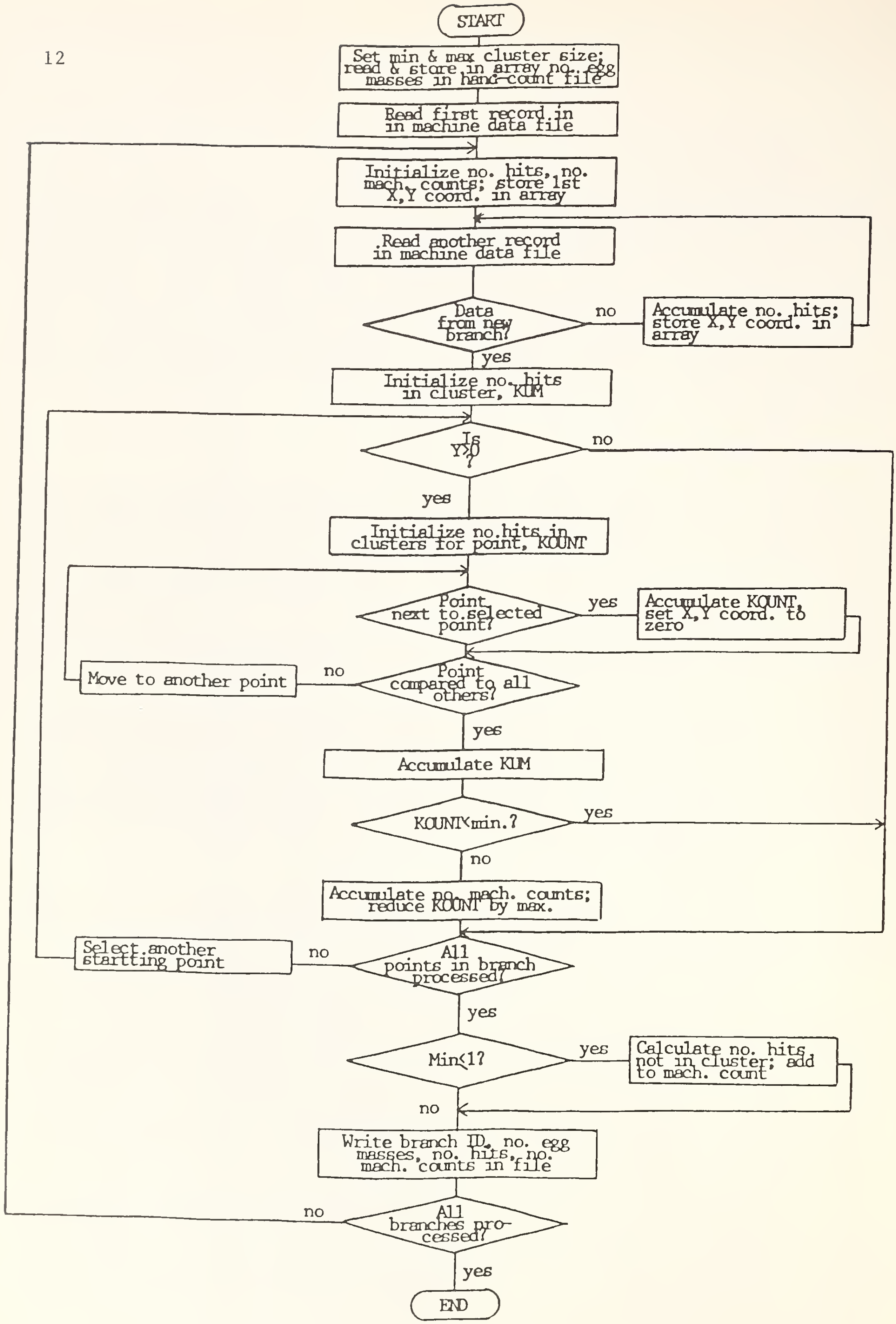

Figure 6. Flowchart showing computational steps involved in the spatial analysis of detailed machine data.

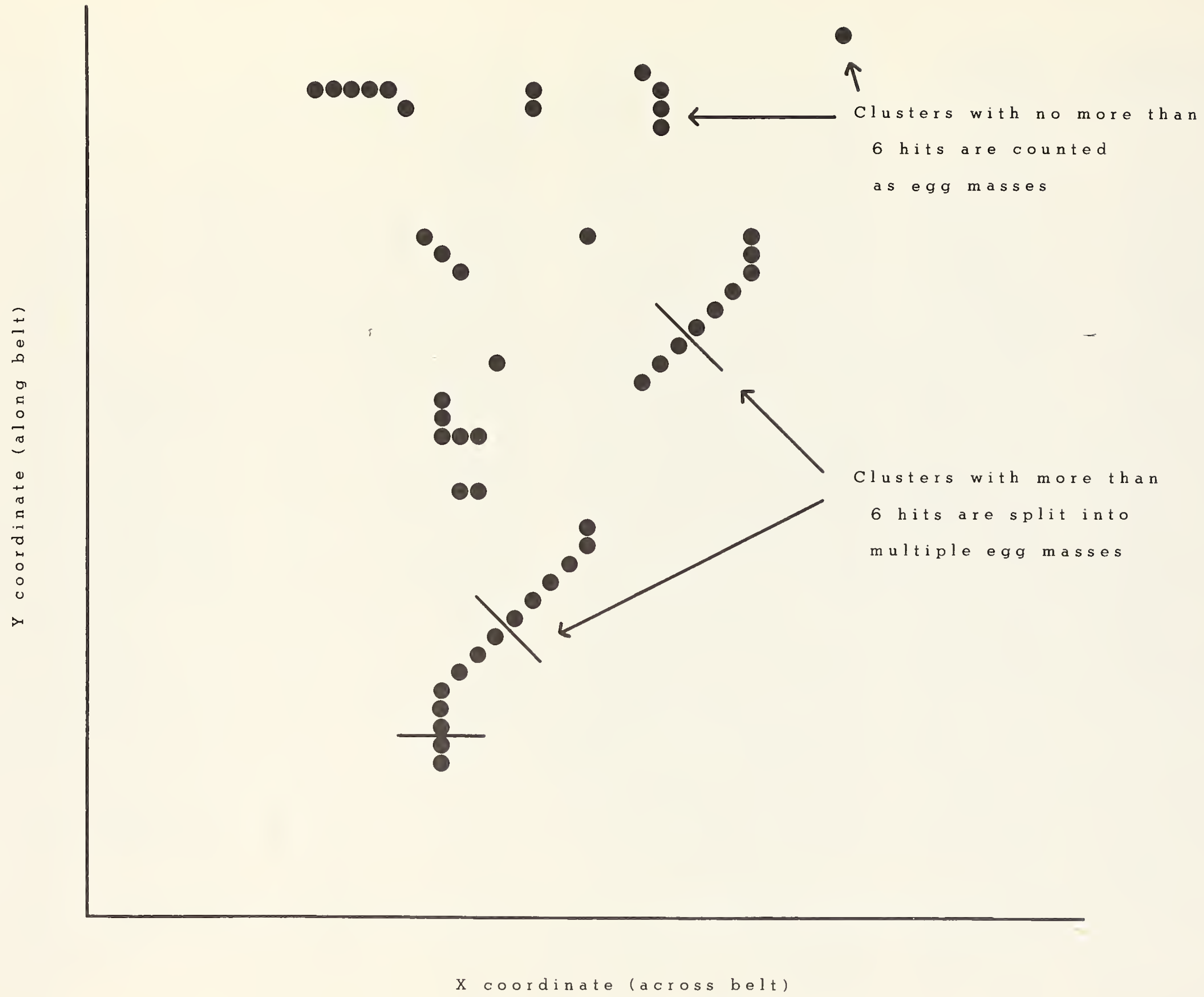

Figure 7. Illustration of spatial analysis effects when the minimum and maximum numbers of adjacent hits in an egg mass are set at 1 and 6 respectively.

SPECTRAL ANALYSIS - During the machine scanning operation, a spot is classified as either a "hit" or "no-hit" based on whether the peak violet and green/violet ratio fall within a window of values. The minimum and maximum values for this window were determined by reading calibration samples of egg masses. For this study, the minimum-maximum values of 125-250 for the violet intensity and 0.15-0.40 for the green/violet ratio were set based on readings made on 20 egg masses in the calibration sample.

This method of setting threshold between hit and no-hit is adequate if the spectral values of egg mass reflectance are distributed in a rectangular window as illustrated in Figure 8. However, if the spectral values are distributed in ellipses, which approximate the normal distribution, then using the spectral window to define the threshold would be inadequate. Such a window would allow too many spots to be counted as hits.

In such a case, a spectral analysis would be useful in improving machine performance by redefining the hit/no-hit threshold based on the principle of maximum likelihood classifiers. Two assumptions made here are that: (1) the distribution of spectral values of egg masses are normally distributed; and (2) the calibration sample of egg masses are representative of all the egg masses with respect to their fluorescence characteristics under ultraviolet light. The principle of this classification approach is illustrated in Figure 8. With the calibration data, normal distribution ellipses for a set number of standard deviations around the mean of the calibration data are drawn through the use of the Mahalanobis distance (Morrison 1976). These ellipses set the critical Mahalanobis distances. Shown in Figure 8 are ellipses corresponding to critical Mahalanobis distances for 1, 1.5, and 2 standard deviations around the mean.

The procedures for performing the reclassification of points based on the maximum likelihood classifier principle are depicted in Figure 9 (this is a modification of Figure 6; two operations were added at points A and B).

At point A of the flowchart the critical Mahalanobis distance is computed by:

$$\text{CRIDIS} = F'\Sigma^{-1} F$$

Where F' = [CFR*SV CFR*SG CFR*SR]

CFR: multiple of number of standard deviations (1, 1.5, or 2) used to set critical distance
SV: standard deviation of violet intensities
SG: standard deviation of green intensities
SR: standard deviation of green/violet ratios
Σ^{-1}: inverse of the covariance matrix of calibration data

At point B once a record is read, the Mahalanobis distance for the point is computed by:

$$\text{DMAH} = D'\Sigma^{-1} D$$

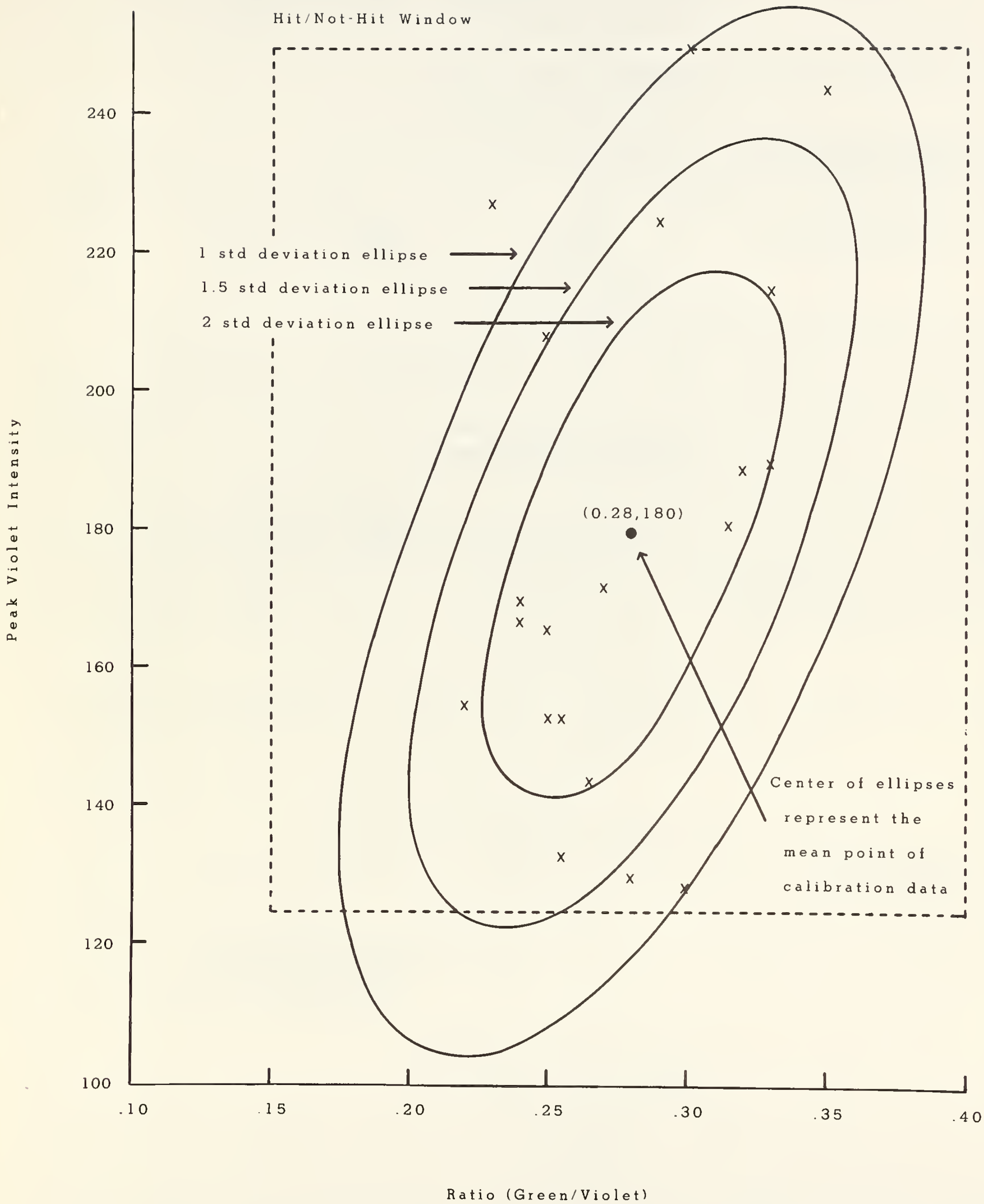

Figure 8. Hit/no-hit thresholds defined by a rectangular window and ellipses resulting from a maximum likelyhood classifier.

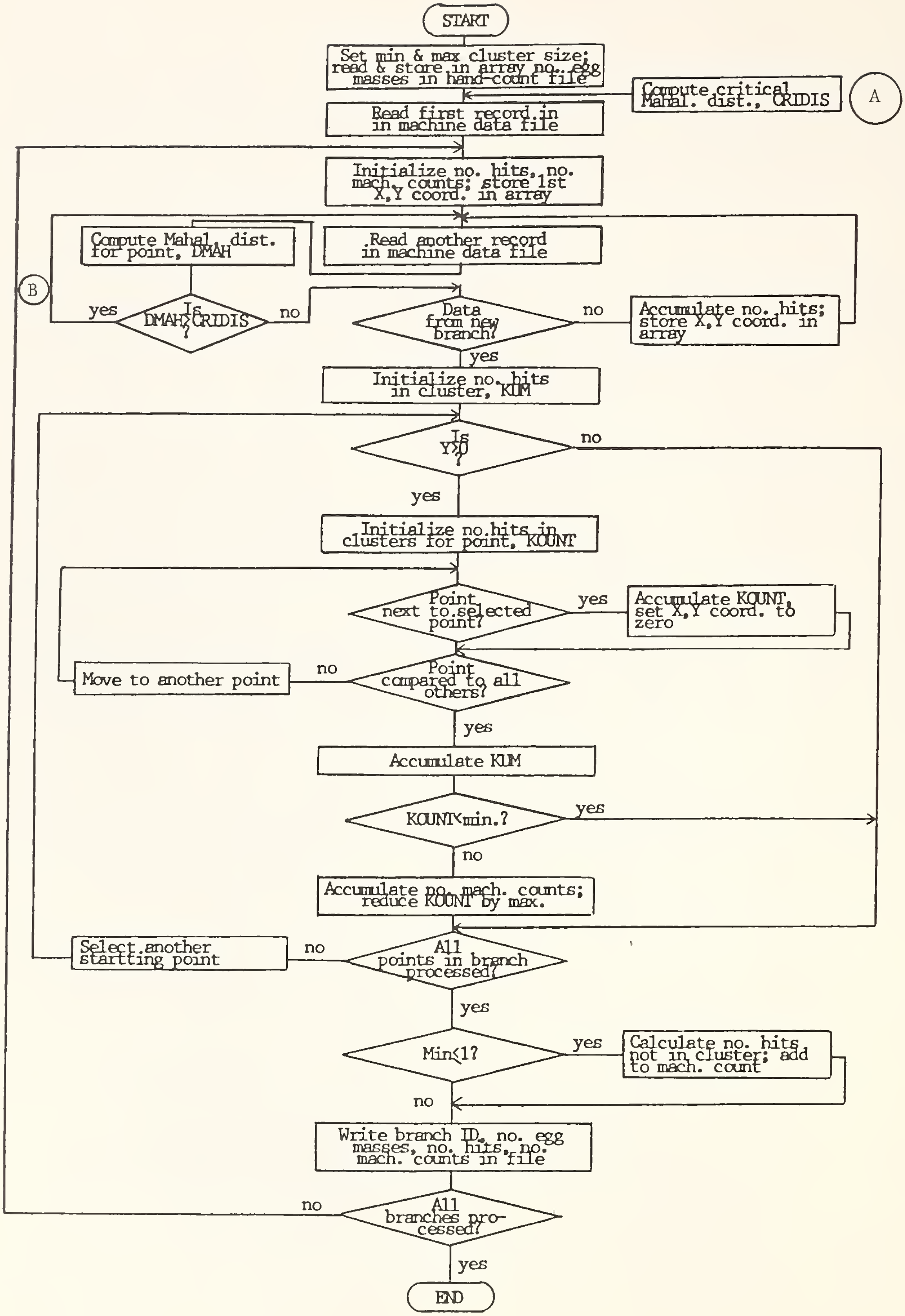

Figure 9. Flowchart showing computational steps involved in performing combined spatial/spectral analysis of detailed machine data.

Where D' = [(V-AV) (G-AG) (R-AR)]
V: violet intensity at point
G: green intensity at point
R: green/violet ratio for the point
AV, AG, and AR are average violet, green, and ratio values of calibration data as defined above.

This distance is then compared to the critical distance. If the distance is greater than the critical distance, the point is classified as no-hit and another record is read. Otherwise, the computer program continues the processing of a hit.

CORRELATING MACHINE COUNTS WITH MANUAL COUNTS -

A measure of the accuracy of the machine in counting egg masses is the correlation between the machine counts (x) with manual counts (y) (considered for the purpose of this study as the actual number of egg masses). Correlation coefficient is a good measure of accuracy in this case because with good correlation the machine counts can be adjusted to provide good estimates of the number of egg masses regardless of any "bias".

The correlation coefficients between the machine counts and manual counts for each location/host/tree condition class within each spatial data reduction method (Table 2 is a listing of all the methods) were computed. The table of correlation coefficients was reviewed and a minimum/maximum cluster size combination, which provided consistently high correlations, was used in combination with spectral data analysis.

With the selected spatial method (cluster size), the spectral data screening was applied. The various combinations of number of spectral variables and size of ellipses evaluated are listed in Table 2.

MACHINE VERSUS MANUAL COUNTING EFFICIENCIES -

For the purpose of comparing the amount of time spent in manual and machine counting, detailed records of starting and stopping times for all tasks were kept. The time spent in marking and cutting branches as well as scanning branches were computed. The time spent for manual counting included time spent to pick needles with egg masses from the branches and to examine and re-examine the foliage. Both machine and manual counting times were then summarized and compared.

RESULTS AND DISCUSSION

CORRELATION OF NUMBER OF HITS WITH MANUAL COUNTS -

The correlation coefficients between numbers of hits counted by the egg mass counter and numbers of egg masses are shown in Table 3. The egg masses were broken down to new egg masses and all (new plus old) egg masses. This table was derived from the summary data for all 525 branches.

Table 2. Listing of parameters used in the spatial/spectral analyses of detailed machine data.

Method	Cluster Size		Spectral Data	No. of SD for Critical Mah. Distance	Remarks
	Min	Max			
A	1	6	N.A.	N.A.	
B	1	5	N.A.	N.A.	
C	1	4	N.A.	N.A.	
D	1	3	N.A.	N.A.	
E	1	2	N.A.	N.A.	
F	2	6	N.A.	N.A.	
G	2	5	N.A.	N.A.	
H	2	4	N.A.	N.A.	
I	2	3	N.A.	N.A.	
J	2	2	N.A.	N.A.	
K	3	6	N.A.	N.A.	
L	3	5	N.A.	N.A.	
M	3	4	N.A.	N.A.	
N	3	3	N.A.	N.A.	
D 1	1	3	V,G, Ratio	2.0	CRIDIS = 29.7103
D 2	1	3	V,G, Ratio	1.5	CRIDIS = 16.7121
D 3	1	3	V,G, Ratio	1.0	CRIDIS = 7.4276
D 4	1	3	V, Ratio	2.0	CRIDIS = 5.9634
D 5	1	3	V, Ratio	1.5	CRIDIS = 3.3544
D 6	1	3	V, Ratio	1.0	CRIDIS = 1.4909

For 3 variables DET = 33,030.0313
For 2 variables DET = 19,397.5293
N.A. Not applicable

Table 3. Correlation between number of egg masses and number of hits recorded by the egg mass counter; data used in the computation came from manual counting and machine scanning of all 525 branch samples.

Location/Host/ Condition Class	Mach Counts (No. Hits)	No. New Egg Masses	Corr with Mach Counts			Total No. Egg Masses (New + Old)	Corr with Mach Counts		
			Bottom	Top	Total		Bottom	Top	Total
All	27,647	3,254	.06	.05	.06	5,474	.15	.15	.15
ID GF Good	95	1	.38	.01	.30	5	.21	-.26	.07
ID GF Int	302	7	.14	-.05	.12	19	.33	-.03	.30
ID GF Poor	72	4	.11	-.04	.02	8	.16	-.13	-.03
ME BF Good	2,670	58	.12	-.07	.05	103	.11	.06	.10
ME BF Int	1,026	755	.19	.10	.16	1,117	.26	.21	.25
ME BF Poor	1,825	596	.09	.14	.13	978	.20	.10	.18
ME RS Good	194	156	-.08	.16	-.05	204	-.09	.15	-.06
ME RS Int	365	165	.08	.20	.17	222	.03	.10	.08
ME RS Poor	440	342	.45*	.49*	.62*	497	.56*	.10	.67*
MT DF Good	392	192	-.15	.05	-.07	316	-.05	.01	-.03
MT DF Int	1,429	249	.32	.13	.28	453	.30	.13	.27
MT DF Poor	4,244	336	.24	.62*	.46*	548	.02	.27	.14
NM WF Good	4,102	53	.46*	.57*	.56*	102	.42*	.55*	.52*
NM WF Int	5,778	174	-.13	.02	-.06	477	-.24	-.08	-.19
NM WF Poor	4,713	166	-.08	.01	-.04	425	.19	.23	.24

* Significant at $p \leq 0.01$

As shown in the table, the total number of hits counted by the machine is 27,647 versus 3,254 new egg masses, a ratio of more than 8 to 1. Even when the old egg masses are added to the counts of egg masses, the ratio of machine count versus the total egg masses is still 5 to 1. The ratio of machine count over the number of new egg masses is highly varible from one location/host/tree condition class to another (95 to 1 for ID GF Good class to almost one to one for the ME RS Good class).

The correlation coefficients between the numbers of hits and the numbers of new egg masses are significant (at 0.01 significance level) only for 3 of the 15 location/host/tree condition classes (ME RS Poor, MT DF Poor, and NM WF Good). Even for these three classes, the highest correlation coefficient is only 0.62 which indicates that only 39 percent of the variation in the data is explained by the linear regression relationship between the two variables (R^2 = 0.39). Higher correlation coefficients must be obtained in further tests before the egg mass counter can be put into operational use.

For a visual illustration of this poor correlation between the machine and hand counts, a scatterplot of the counts for the ME RS Poor class (class where the correlation is highest) is shown in Figure 10. Also shown in this figure is the regression line for predicting number of egg masses from the machine counts. The magnitude of the residual error of 6.22 is large as compared to the average number of egg masses per branch of 9.77. Again the R^2 value of 0.39 is not anywhere near the performance of the Prototype I machine's performance where the R^2 was reported to be 0.97.

CORRELATION AFTER SPATIAL ANALYSIS -

As discussed earlier, detailed data were available for 239 of the 525 branches collected. Therefore, spatial and spectral analyses which required coordinates and violet and green intensities at each hit point could only be performed for the 239 branches.

Estimates of number of egg masses after spatial analysis and resulting correlation coefficients between these estimates and the number of egg masses are presented in Table 4. It should be noted that only one location/host/tree condition class has significant correlation (at 0.01 significance level) between the numbers of hits and the number of egg masses among the eight classes. After spatial analysis, the same class, ME RS Poor, remains the only class where correlation between machine based estimates and the number of egg masses is significant. A very slight improvement in the coefficient is observed as a result of the spatial analysis. The highest correlation coefficient was obtained with cluster size of 1-3 hits for each egg mass.

CORRELATION AFTER SPATIAL AND SPECTRAL ANALYSES -

The machine based estimates of numbers of egg masses after application of spectral analysis in combination with the best spatial analysis method are shown in Table 5. The correlation coefficients also shown in this table indicate very slight improvement resulting from the spectral analysis. However, the correlation for class MT DF Int which was just below the

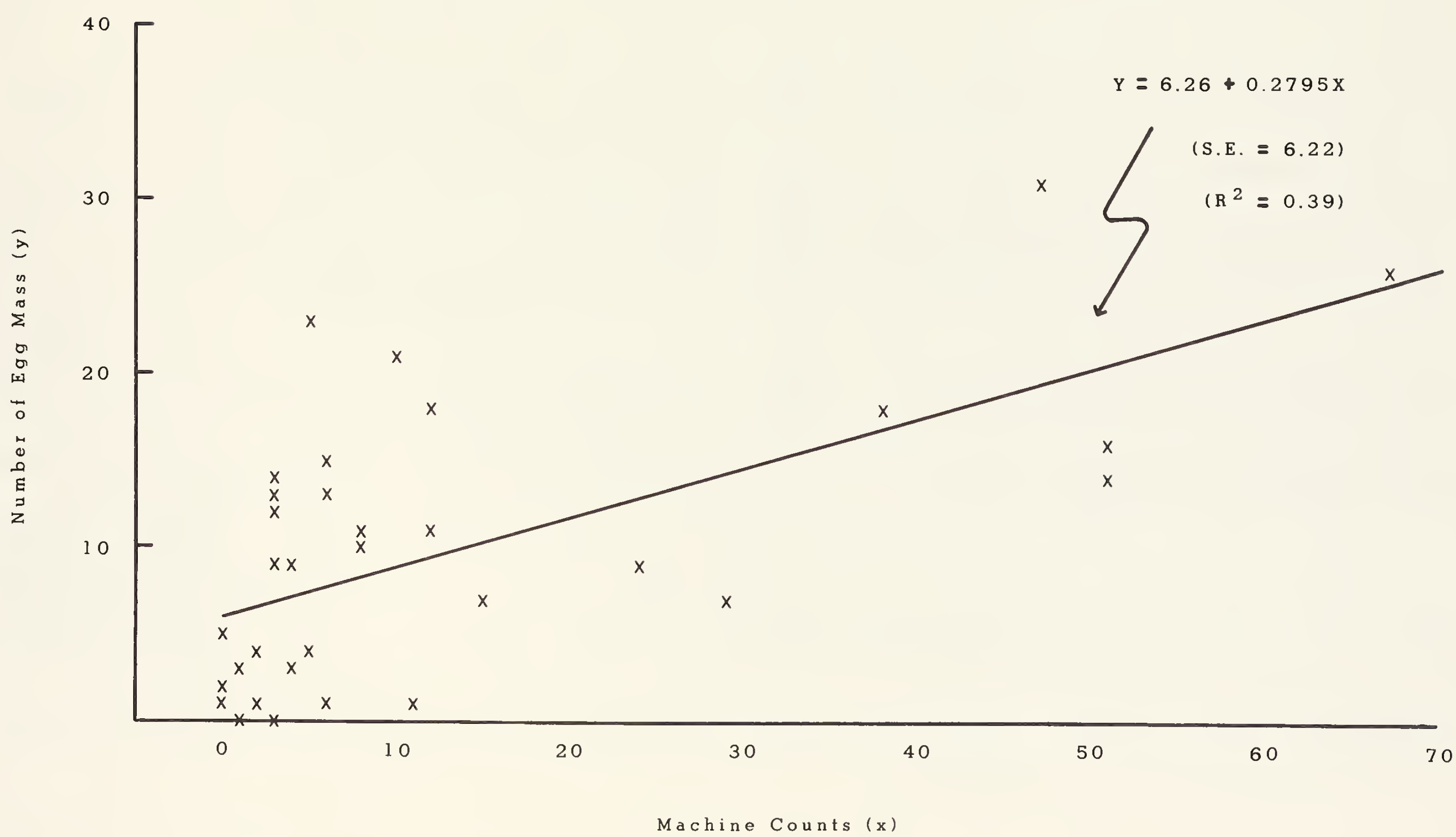

Figure 10. Scattergram of machine counts versus number of new egg masses for location/host/tree condition class "Maine red spruce" where correlation between machine and manual counts is strongest; the regression line and equation for predicting number of new egg masses from machine counts are also shown.

Table 4. Comparison of manual counts of spruce budworm egg masses with machine counts after spatial analysis and correlation with numbers of egg masses (in parentheses).

Host Tree Condition Class	No. of Branches	No. of New Egg Masses (Hand Count)	No. of Hits	Spatial Analaysis Method													
				A	B	C	D	E	F	G	H	I	J	K	L	M	N
All	239	2108	7072 (.04)	5627 (.03)	5628 (.03)	5632 (.03)	5676 (.04)	5869 (.03)	1153 (.05)	1153 (.05)	1154 (.05)	1158 (.04)	1203 (.05)	237 (.02)	237 (.02)	237 (.02)	238 (.02)
BF Good	35	58	2351 (-.01)	1946 (-.03)	1946 (-.03)	1946 (-.03)	1953 (-.03)	2000 (-.03)	344 (.04)	344 (.04)	344 (.04)	344 (.04)	351 (.05)	54 (.14)	54 (.14)	54 (.14)	54 (.14)
BF Int	29	590	615 (.29)	518 (.30)	518 (.30)	518 (.30)	520 (.30)	504 (.29)	80 (.27)	80 (.27)	80 (.27)	80 (.27)	82 (.26)	15 (-.04)	15 (-.04)	15 (-.04)	15 (-.04)
BF Poor	27	482	1489 (-.19)	1182 (-.15)	1183 (-.15)	1184 (-.15)	1196 (-.16)	1234 (-.17)	240 (-.20)	240 (-.20)	241 (-.20)	242 (-.20)	255 (-.20)	50 (-.28)	50 (-.28)	50 (-.28)	51 (-.27)
DF Good	35	192	391 (-.09)	337 (-.09)	337 (-.09)	337 (-.09)	339 (-.09)	344 (-.08)	45 (-.06)	45 (-.06)	45 (-.06)	45 (-.06)	47 (-.06)	7 (-.01)	7 (-.01)	7 (-.01)	7 (-.01)
DF Int	35	249	1369 (.31)	1027 (.34)	1027 (.34)	1029 (.34)	1039 (.34)	1094 (.33)	263 (.23)	263 (.23)	263 (.23)	265 (.23)	275 (.24)	65 (.13)	65 (.13)	65 (.13)	65 (.13)
RS Good	23	104	149 (-.03)	123 (-.09)	123 (-.09)	123 (-.09)	125 (-.07)	128 (-.06)	19 (.01)	19 (.01)	19 (.01)	19 (.01)	21 (.03)	5 (.13)	5 (.13)	5 (.13)	5 (.13)
RS Int	28	140	351 (.15)	248 (.26)	248 (.26)	249 (.25)	254 (.23)	268 (.21)	77 (.06)	77 (.06)	77 (.06)	78 (.05)	83 (.03)	19 (-.08)	19 (-.08)	19 (-.08)	19 (-.08)
RS Poor	27	293	357 (.63)*	246 (.66)*	246 (.66)*	246 (.66)*	250 (.67)*	268 (.64)*	85 (.59)*	85 (.59)*	85 (.59)*	85 (.59)*	89 (.60)*	22 (.46)*	22 (.46)*	22 (.46)*	22 (.46)*

* Significant at $p \leq 0.01$

Table 5. Comparison of manual counts of spruce budworm egg masses with machine counts after spatial/spectral analysis and correlation with numbers of egg masses (in parentheses).

Host Tree Condition Class	No. Branches	No. Egg Masses	No. Hits	Machine Count After Spatial Analysis D	Machine Count After Spatial/Spectral Method					
					D-1	D-2	D-3	D-4	D-5	D-6
All	239	2108	7072 (.04)	5676 (.04)	5305 (.03)	4712 (.04)	3436 (.04)	4391 (.05)	3205 (.06)	1591 (.03)
BF Good	35	58	2351 (-.01)	1953 (-.03)	1798 (-.04)	1577 (-.03)	1155 (-.03)	1489 (-.01)	1110 (-.02)	520 (.01)
BF Int	29	590	615 (.29)	520 (.30)	490 (.27)	439 (.28)	438 (.25)	424 (.27)	324 (.27)	144 (.28)
BF Poor	27	482	1489 (-.19)	1196 (-.16)	1092 (-.15)	966 (-.17)	688 (-.15)	912 (-.18)	757 (-.17)	282 (-.14)
DF Good	35	192	391 (-.09)	339 (-.09)	330 (-.07)	299 (-.05)	220 (-.09)	280 (-.06)	203 (-.09)	113 (-.04)
DF Int	35	249	1369 (.31)	1039 (.34)	980 (.33)	848 (.34)	578 (.39)	752 (.37)	494 (.42)*	247 (.42)*
RS Good	23	104	149 (-.03)	125 (-.07)	123 (-.07)	120 (-.07)	97 (-.07)	111 (-.07)	83 (.02)	54 (-.10)
RS Int	28	140	351 (.15)	254 (.23)	247 (.25)	231 (.25)	177 (.24)	204 (.25)	158 (.25)	100 (.20)
RS Poor	27	293	357 (.63)*	250 (.67)*	245 (.67)*	232 (.66)*	191 (.66)*	219 (.68)*	172 (.68)*	112 (.58)*

* Significant at $p \leq 0.01$

significant level was brought up to the significant level when the hit-no-hit threshold was set at 1.5 and 1 standard deviation using the violet intensity and green/violet ratio.

Figure 11 illustrates the improvement in the correlation between machine based estimates and the hand counted number of egg masses resulting from the spatial and spectral analyses for two classes, MT DF Int and ME RS Poor.

COUNTING TIME EFFICIENCIES -

The summary statistics for manual and machine counting times are shown in Table 6. Counting egg masses with a machine, if an accurate count can be obtained, would save on the average 26 minutes per branch. The time required with machine operation, including both upper and lower scan, is approximately one-third of the manual counting.

Table 6. Comparison Between Spruce Budworm Egg Masses Hand and Machine Counting Times (Minutes)

Cutting Time (in Minutes)		Counting Time	
		Machine	Hand
Average/branch	2.00	13.7	39.90
Standard deviation	1.20	6.8	25.50
Minimum	0.75	4.0	4.75
Maximum	9.00	43.0	252.00

CONCLUSIONS AND RECOMMENDATIONS

Results obtained in this evaluation suggest that the egg mass counter Prototype II will need further refinement before it can be used operationally. Further research must be undertaken to determine (1) the best spatial and spectral calibration techniques to use; (2) if calibration needs to be performed separately for each location/host/tree condition class; (3) if regression equations need to be developed to transform machine counts into the estimates of the number of egg masses; and (4) if regression equations are needed, it must be determined whether each location/host/tree condition class requires a unique equation or if one equation can be used in all classes. Other applications of the machine should also be investigated.

In light of the foregoing discussion, we suggest that additional studies should focus on the following:

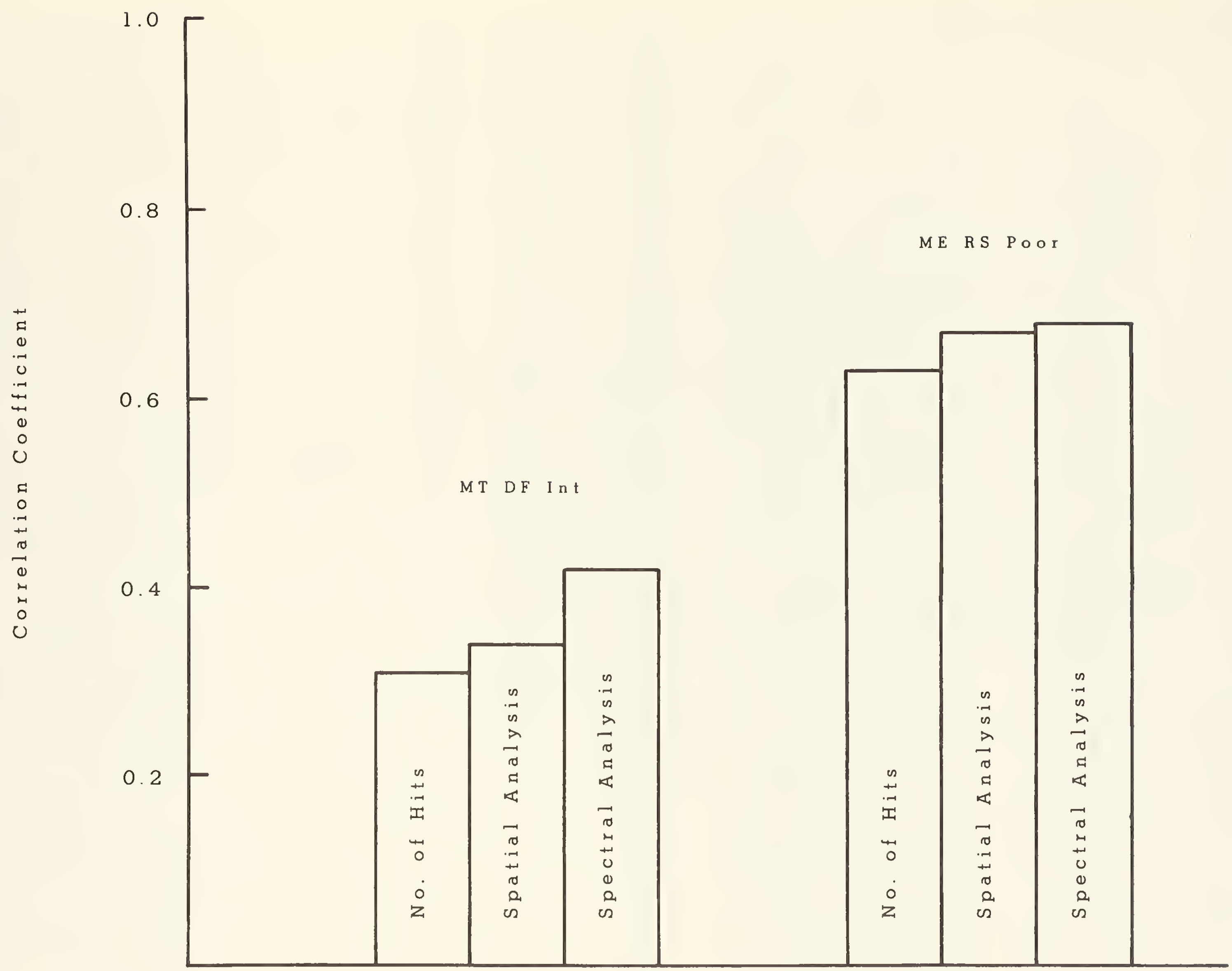

Figure 11. Improvement in the correlation resulting from spatial and spectral analyses for two location/host/tree classes where correlation between hand counts and machine counts are statistically significant.

1. Evaluation of machine stability over time and fluctuation in the electric current. This test may be performed by passing an object with uniform reflection characteristics through the machine a number of times and recording the readings in violet and green. If periodic recalibration is required due to instability, it would be desirable to determine how often recalibration must be done.

2. Elimination or reduction of branch vibrations on the conveyor belt by replacing the stepper motor. Since Prototype II was manufactured, better stepper motors have become available. These new motors would reduce branch vibrations on the conveyor belt to a minimum and would in turn improve the accuracy of spectral data readings.

3. Determination of the best method for training the machine's software to recognize egg masses. This study will require scanning branches and recording all detailed data for all points. These branches, collected from various locations, hosts, and tree conditions, must be mapped to serve as "ground truth" samples where positions of all egg masses are known. Spectral signatures of all objects on the branches can be extracted and a scheme to perform discrimination between objects can be designed for implementation.

4. Development of a scheme to perform a spatial analysis in order to account for the geometry of the egg masses. Data collected in (2) can be used for this purpose.

5. Application of discrimination criteria and spatial data manipulation methods developed in (2) and (3) to the data set. Develop and test regression equations for transforming machine counts into estimates of the number of egg masses for all location/host/tree condition classes.

6. Evaluation of machine performance on a new branch sample with respect to stability of discrimination criteria, spatial data manipulation method, and regression equations developed in (2), (3), and (4).

7. Investigate other applications of the machine, for example, Could the unit be used to detect and count spray droplets on foliage by adding a fluorescent tracer to the spray tank mix?

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